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Research on the method for producing complex SiC_P/Al composite disk brake castings

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The casting properties of a SiC_P/Al composite are analyzed in this paper and the methods for producing complex castings of SiC_P/Al composite disk brake together with their difficulty are discussed. An adjustable vacuum pressure casting method is established on the basis of a normal adjustable pressure casting method. The SiC_P/Al composite disk brake casting is made with the established method. The results show that the adjustable vacuum pressure casting is a successful casting method for producing SiC_P/Al composite castings of large dimensions and complex structures, which gives few defects as confirmed by X-ray real- time image system.

Key words: SiC_P/Al composite, Disk brake, Adjustable vacuum pressure casting.

Introduction

Lightweight and effective braking are key technologies for the development of high-speed train. Conventional iron and steel disk brakes used on current high-speed trains can ensure effective braking. However, it increases the unsprung weight of the train using iron and steel brake disks and creates higher energy waste in application. SiC_P/Al composites are one of the suitable lightweight materials for making disk brake especially because of their good properties such as good wear resistance, high specific strength and good thermal conductivity. The selection of SiC_P/Al composite for making disk brakes is now receiving more and more attention in high-speed train application.

According to the recent studies [1, 2], fabrication methods of SiC_P/Al composites have achieved good results in both reducing production cost and obtaining good properties of SiC_P/Al composites. But the application of the composites especially on complicated structure parts is still very limited. Normally the casting method is one of the most suitable methods to produce parts with complicated structure. However, it is difficult to produce sound castings from SiC_P/Al composites because of their poor casting properties. There are three main reasons that cause poor casting properties of SiC_P/Al composites. Firstly, the flow ability of the liquid composites is about 50%~60% of their liquid matrix aluminum because of the addition of SiC particles. Secondly, the surface energy of the liquid composites is greater than its liquid matrix aluminum, which prevents gas from escaping from the melt and it is easy to form gas hole defects in castings during the filling process. Finally, the low feeding ability during solidification process caused by poor flow ability will easily create porosities in castings and then lower the properties of SiC_P/Al composite castings. Therefore, it is important to develop a suitable casting method to promote the application of this material especially on complicated structure parts.

The structure of a SiC_P/Al composite disk brake as shown in Fig. 1 is very complex. It is so difficult to make a sound casting with normal casting methods such as the gravity casting method. An adjustable vacuum pressure casting method is established in this paper based on the normal adjustable pressure casting method. A sound disk brake casting from the SiC_P/Al composite material is made with the established method, which is

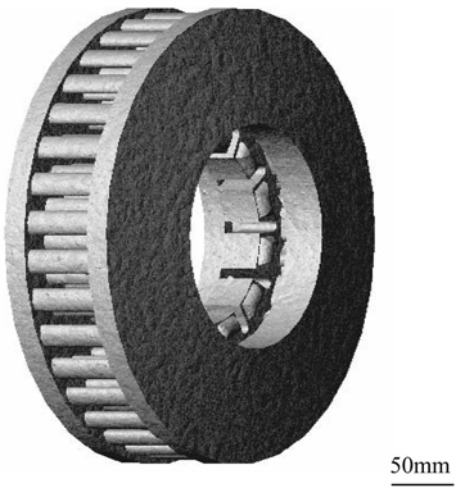

Fig. 1. Disk brake model.

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confirmed by by X-ray real- time image system.

Adjustable Vacuum Pressure Casting Method

Three casting processes need to be carefully controlled in the casting technology in order to obtain sound castings of SiC_P/Al composites, Firstly, the filling pressure and speed need to be controlled to achieve fast and smooth filling of liquid SiC_P/Al composites into the mold cavity without the occurrence of turbulence flow. Secondly, the mold cavity and the filling process needs to be under a vacuum circumstance to help the gas escape from the melt. Thirdly, the feeding pressure needs to be increased during solidification process in order to make the casting solidify under high pressure to reduce the shrinkage. After comparison of various casting technologies and methods, it is found that the adjustable vacuum pressure casting method is an appropriate method to produce SiC_P/Al composite castings. Figure 2 shows the principle of the normal adjustable pressure casting method. The resin sand mold is put in the top vacuum chamber, and the melt from the vacuumed bottom crucible is forced to enter the sand mold through a connection tube by the pressure difference between the top vacuum chamber and the vacuumed bottom crucible. Then the casting solidifies under higher pressure to achieve enough feeding ability.

Figure 3 shows the pressure curve of the normal adjustable pressure casting method. It can be seen that the normal adjustable pressure casting process can be divided into five steps which are decompression, filling mold, raising pressure, maintaining pressure and unloading mould. This method can ensure that not only the cavity filling process is in a vacuum situation, but also the solidification of the casting is in a vacuum situation with some feeding pressure as well if compared to the normal gravity casting process. However, both pressures in the crucible and the chamber change from vacuum to a positive pressure during the steps of maintaining pressure with the pressure difference between the vacuum chamber and crucible only held at the filling pressure difference level. The pressure change from a vacuum to a positive in the top chamber gives no help for gases to escape from melt after filling process and during solidification process. The small pressure difference in the maintaining pressure process gives less feeding pressure during the solidification process. It can be seen that normal adjustable pressure casting method is not so good for producing SiC_P/Al composites castings because gas hole and porosity defects are easy to be formed in the castings.

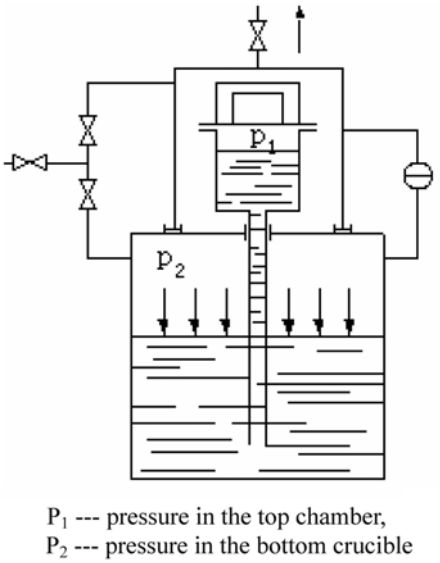


Fig. 2. Illustration of the principle for the adjustable pressure casting method.

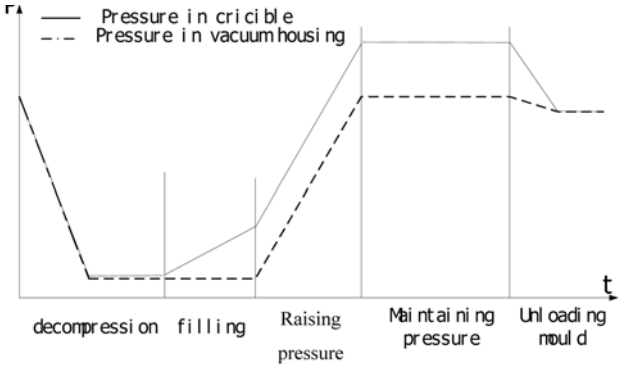


Fig. 3. Pressure curve of the normal adjustable pressure casting method.

On the basis of a study of the normal adjustable pressure casting method, a further improved method called adjustable vacuum pressure casting method is proposed to make it more suitable for producing the SiC_P/Al composites castings. In the proposed method, both the chamber and crucible pressures are changeable during the filling and solidifying processes. In other words, it is possible to keep the chamber under the vacuum and increase the pressure in the crucible during the filling and solidifying processes. The pressure curve of the improved method is shown in Fig. 4.

The adjustable vacuum pressure casting method can

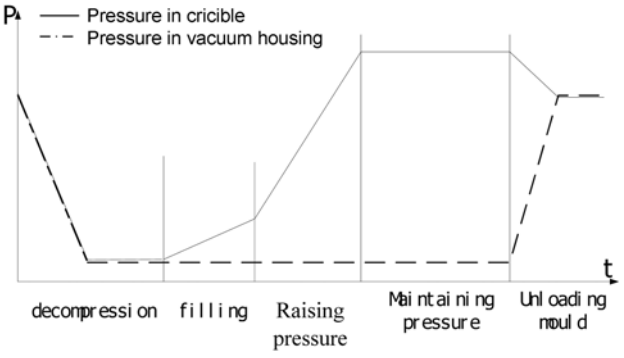


Fig. 4. Pressure curve of the adjustable vacuum pressure casting method.

make the SiC_P/Al composite melt fill into the mold cavity and solidify under a vacuum atmosphere and apply more feeding pressure than the normal adjustable pressure casting method. The advantages to obtain good quality SiC_P/Al composite castings are as follows.

(1) Improved filling process

The mold cavity can be filled with melt at a flow velocity that can easily be modified by adjusting the pressure difference between the top chamber and bottom crucible. The turbulent liquid flow can be avoided and defects caused by the poor flow ability of the SiC_P/Al composite melt can be eliminated.

(2) Reduced gas and inclusion occurrence in castings

The gas hole can be greatly reduced during the filling process because the cavity is filled with melt under a vacuum atmosphere. The melt is transferred from the vacuumed crucible to the mold cavity through a connection tube with one end embedded in the molten melt in the crucible, which can avoid aluminum oxide inclusions on the liquid surface enter into mold cavity.

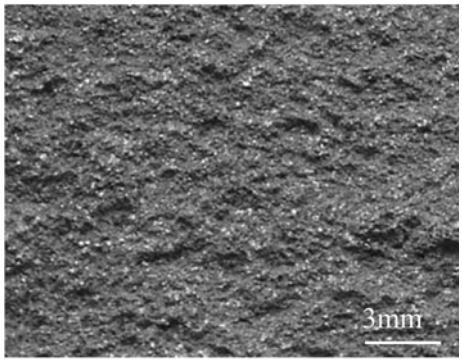
(3) Improved feeding ability

As shown in Fig. 4, the pressure difference between the crucible and chamber of the adjustable vacuum pressure casting method can be 4 times higher than that of the normal adjustable pressure casting method during the pressure maintaining period. The gating system through which all melt flow into the mold is used as the feeding path and a directional solidification model can be easily achieved with a proper casting technology design. The casting will be then better fed with greater feeding pressure during solidification process Therefore less shrinkage and porosity will occur in the casting.

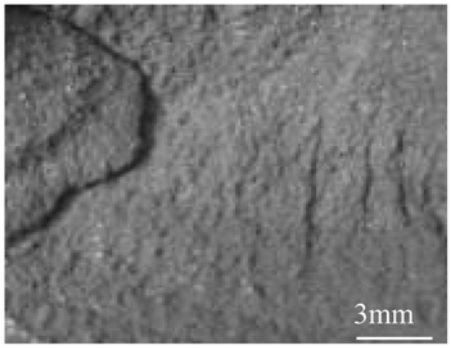
It can be seen that the adjustable vacuum pressure casting method is especially suitable for producing SiC_P/Al composite castings of large dimensions and complex structures that are easy to form gas holes and difficult to achieve good feeding results.

Application of the Method in SiC_P/Al Disk Brake Castings

A SiC_P/Al composite disk brake is produced with the adjustable vacuum pressure casting method established in this paper. The vacuum pressures in both top chamber and bottom crucible are –0.095 MPa before filling step, the filling pressure difference between the vacuum chamber and crucible is 0.2 MPa and 6 seconds for filling time, the holding pressure is 0.08 MPa in the crucible for 10 minutes, while the top chamber is still in –0.095 MPa vacuum pressure during solidification process. Compared to gravity casting, the porosity of the disk brake casting is reduced from 2.3% to 0.85%. The fractures of the runs made by the gravity casting method and adjustable vacuum pressure casting method are shown in Fig. 5. It can be seen that the fracture made by the adjustable vacuum pressure casting method



a. gravity casting method



b. adjustable pressure casting method

Fig. 5. Photos of fractures of the runs.

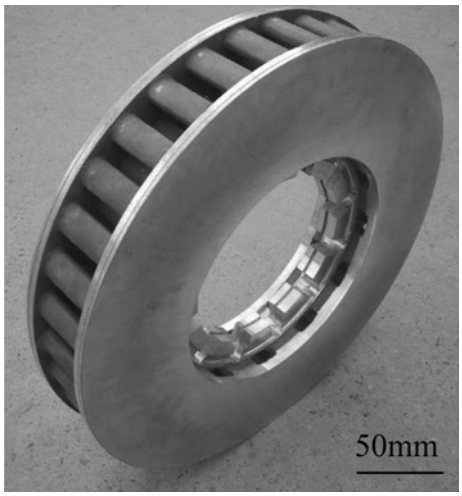


Fig. 6. Photo of the disk brake machined.

is more dense than that made by the gravity casting method. A machined SiC_P/Al composite brake disk produced with the adjustable vacuum pressure casting method is shown in Fig. 6. Non-destructive inspection with a 450 kV industrial X ray real- time image system shows little shrinkage in the disk brake casing as shown in Fig. 7.

Conclusion

(1) An Adjustable vacuum pressure casting method is

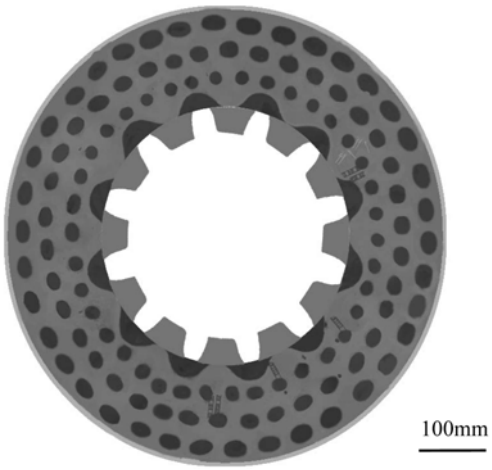


Fig. 7. Picture of X-ray inspection of disk brake made by an adjustable pressure casting method.

developed based on the normal adjustable pressure casting method. The filling and feeding processes are improved significantly with less porosity and shrinkage occurrence the casting.

(2) A SiC_P/Al composite disk brake casting is successfully produced with the adjustable vacuum pressure casting method with 0.85% porosity and little shrinkage found in the casting.

Acknowledgements

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